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HUMAN FACT

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8 May 1959

ENGINEERING DEPARTMENT

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CONVAIR SAN DIEGO CONVAIR DIVISION GENERAL DYNAMICS CORPORATION

CONTENTS

ILLUSTRATIONS

SUMMARY

A series of test exposures of pilot subjects to the simulated thermal environment of a very high performance aircraft cockpit are reported herein. The effectiveness of a current ventilated, full-pressure suit (Goodrich Mark III), was tested in terms of its capability for successfully protecting the pilot subjects from the experimental temperature profile.

Detailed physiological and performance data for the subjects under both test and control conditions are presented, as is a description of the numerous instrumentation problems posed by the dynamic simulation of cockpit thermal conditions. The tests were restricted to a rather small sample of subjects, but there are indications that some peculiar physiological reactions to changing temperature profile may set a different level of tolerance than that shown for steady temperature states. Further research is needed to test this, and such will shortly be underway. With vent-suit protection, the environment tested was quite tolerable to three pilot subjects, though certain design changes and needed developments in protective clothing are indicated.

INTRODUCTION

A step towards clarifying some of the issues involved in accurately forecasting human tolerance to severe thermal environments was taken during 1957 by the Convair bio-technical groups and the results are available.(1) These tests raised several more issues, and in 1958 an attempt was made to resolve as many of the problems as possible. Specifically, the test series began with the following questions to be answered:

1. Can the dynamic cockpit temperature changes associated with high performance and re-entry space vehicles be successfully simulated for human test purposes?*

2. What is the operational suitability of one possible set of cockpit thermal conditions for a Mach 5, 100,000 ft., interceptor over a 45-minute flight profile?

3. What are the psychophysiological effects of exposure to this operational profile --with and without protective equipments?

The improvements which this year's work had over the preceding involved the addition of the more realistic changing temperature profile, the development of more uniform heating conditions, and the considerable increase in realism afforded by a newly developed flight simulator task for the pilot subjects.

The temperature profile employed was developed in conjunction with members of the Thermodynamics and Air Conditioning Groups. It represented

* Current design criteria are based on steady temperature conditions.(2)

a very severe condition which, if biologically acceptable, would provide significant savings in air conditioning efficiency in aircraft in the class of the 1500° F. airplane. It also bore considerable resemblance to the re-entry temperature relationships of certain types of high drag, non-gliding space vehicles.

EXPERIMENTS

Although it was not originally intended, test goal 1, as stated in the Introduction, occupied by far the majority of the engineering effort expended. The principal problems arose in the area of instrumentation reliability and accuracy. The experimental equipment to be described below presented very difficult problems in the maintenance of adequate test records. A particularly stubborn problem arose in the effort to obtain sufficiently accurate measures of rectal temperature. The great importance of this measure to the safety of the test subjects caused the test team to persist in seeking an instrumentation solution. Another major problem concerned the operation of the closed circuit TV system under the severe temperature load. Although these two problems were the most difficult to solve, numerous other difficulties arose which caused the program to be delayed and test runs aborted. As a consequence, the program failed to generate the quantity of data originally hoped for. The data are based to a degree on fragmentary observations made during partially unsuccessful tests as well as on the tests which were completed. Despite these difficulties, it is felt that the potential importance of certain thermal parameters indicated by these data, makes a preliminary report desirable. More thorough testing is planned.

A. Instrumentation

The devices used in this study can be divided into three groups -- the test programming equipment, the environmental measuring equipment, and the subject measuring and safety equipment. Each equipment set is listed on the following page.

A. 1. Programming Equipment - The temperature profile which it was sought to duplicate is shown in Figure 1. The equipment and procedures involved in approximating this profile were as follows: The Hieatt Environmental Chamber was brought to 250°F. An F-102A cabin section was in the chamber, covered by a fiberglass shroud. Plant air at 10 lbs./min. was passed through an alcohol-to-air heat exchanger and delivered into the cabin of the F-102A through a set of piccolo tubes. This held the cabin air to 80°F. and the inner wall temperatures to approximately 115°F. An experimental pilot-subject, dressed in the Goodrich Mark III, full pressure-ventilation suit, was taken into the chamber and placed in the cockpit. The chamber's heaters and fans were turned off during the time that the pilot was getting into the cockpit. The subject would connect his ventilating and breathing air supply from within the cockpit. The air supply to the suit was from the plant compressed air line and was delivered at 80°F. and 10 ft^3/min. The respiratory gas was air, delivered to the helmet on a demand basis. At the start of the run, the fiberglass shroud was lowered permitting the full chamber air temperature to envelope the test specimen. Simultaneously, the chamber heating units were turned on and banks of twenty 1000 watt heating rods on each side of the structure were turned on full. Next a blower was turned on which drew off the hot chamber air and fed it directly into the cockpit. The inlet air temperature to the suit was maintained between 60 - 80°F. by mixing plant air with required amounts of refrigerated air. At

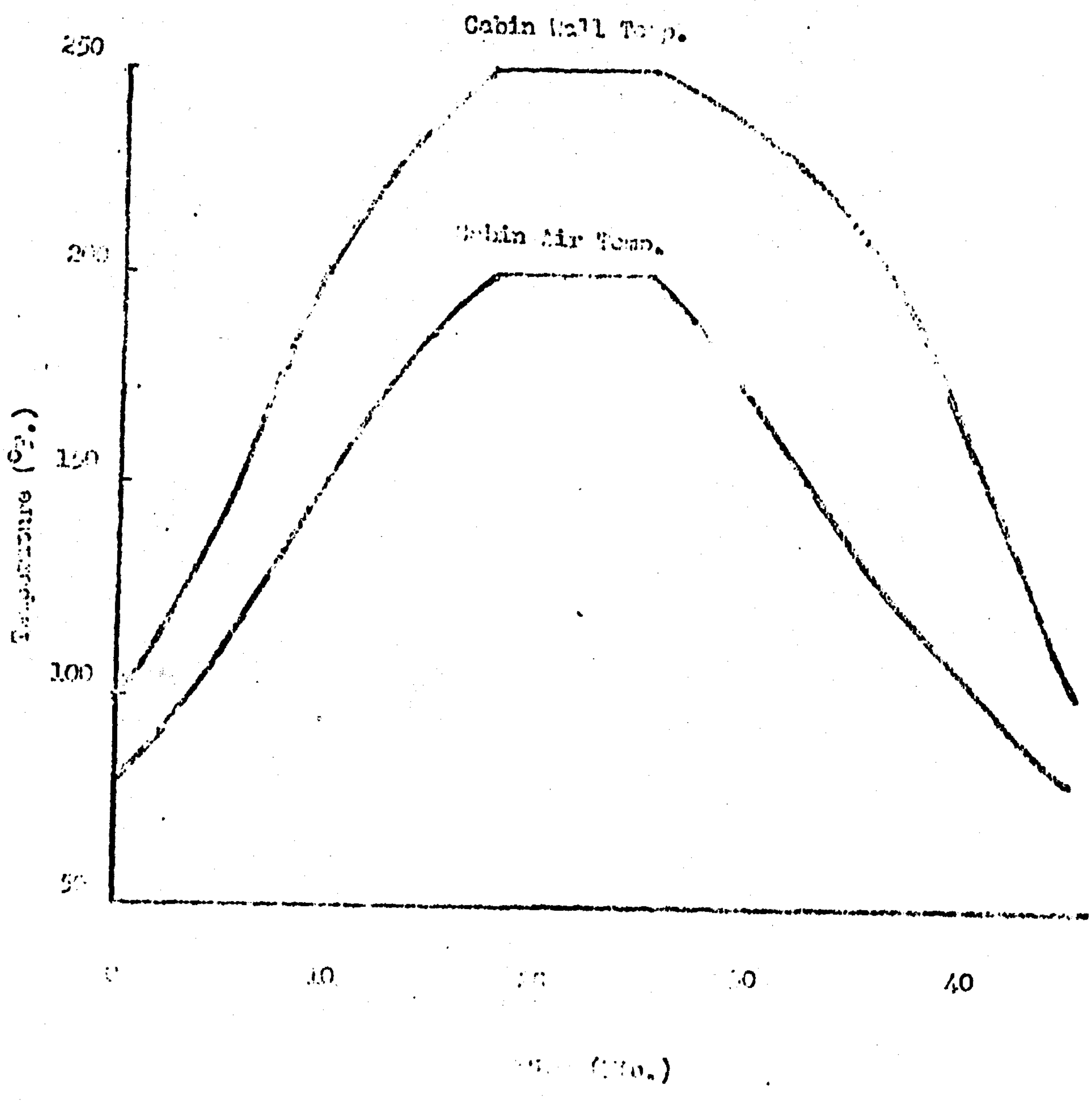

Figure 1.-THEORETICAL HEATING PROFILE FOR TOLERANCE STUDY

the peak of the temperature profile, the following procedures were involved in cooling the vehicle down: the heated air from the chamber to the cockpit was shut down and the refrigerated air supply substituted for it. The main door to the chamber was opened slightly, permitting the heated air to begin emptying out. The chamber heaters were turned off. The actual profile of heating obtained during the three completed runs is shown in Figure 2. It is apparent that it departs rather considerably from the theoretical profile of Figure 1, but is the nearest approximation the equipment would permit. The second programming sub-system involved the flight problem presented to the pilot subjects. Prior to the heat run, each subject was given four training trials on the flight simulator under normal temperature conditions. The last training trial was conducted with the suit on and operating. The equipment and procedure for presenting the flight problem were as follows: The second and third harmonic of a sine wave and a triangular wave form were superimposed and recorded on tape with a 27-minute repeat pattern. The result was a random acoustical signal. The signal was passed through electronic circuitry which produced an analagous random visual signal on a C.R.T. facing the pilot in the cockpit. The C.R.T. had a set of cross-hairs. The pilot was instructed to use a side-stick control and a set of rudder pedals to maintain the randomly moving dot as near the intersect of the cross-hairs as possible.

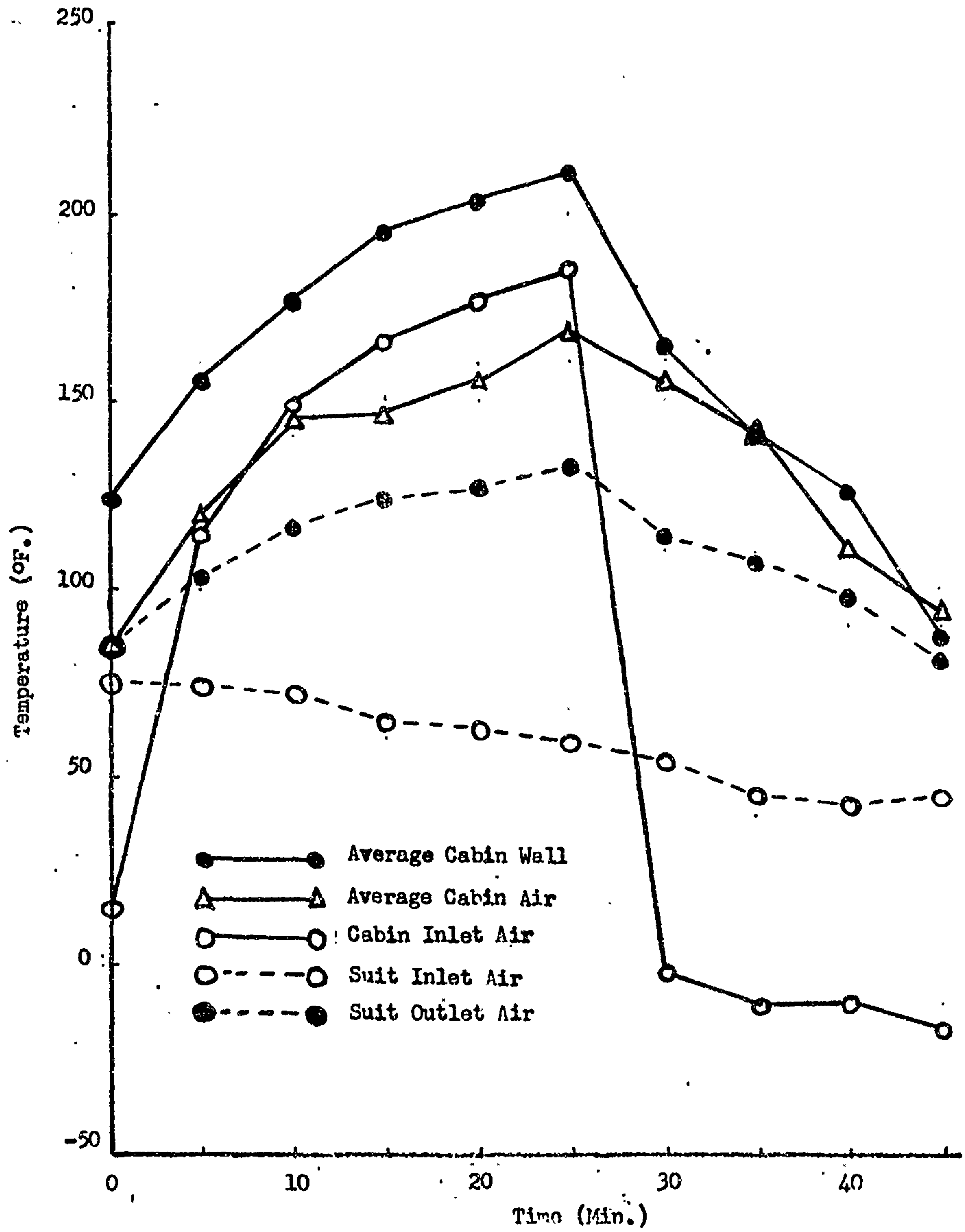

Figure 2.-AVERAGE ENVIRONMENTAL CONDITIONS FOR THREE COMPLETED RUNS - PROTECTED

2. Environmental Measuring Equipment - There were 17 iron-constantan thermocouples attached on the inner walls of the test specimen. There were 20 radiation shielded iron-constantan thermocouples distributed through the cockpit measuring the air temperature. Additional thermocouples were placed at the inlets and outlets to the suit and one on the exterior of the suit on the left thigh. All of these were fed to a Brown Recorder and printed out at 3-minute intervals. In addition, wet and dry bulb measurements were taken just upstream from the suit inlet and just downstream from the suit outlet. Averages of these measurements are shown in Figures 2 and 3. It should be noted that the very severe drop in the cabin inlet air required to cool the cabin is unrealistic in terms of aircraft requirements because of the very large residual heat in the chamber at the point of cool-down which would not be present at the point of aircraft throttle-down.

3. Subject Measuring and Safety Equipment - As in most human tolerance test work, these devices have a dual purpose. First, they supply information to medical personnel for the purpose of indicating the condition of the subject and the necessity for ending a test if safe limits are exceeded. Secondly, they are the basic data for evaluating the effect of the environment on the man and the effectiveness of the various protection devices which may be employed. The following equipment and procedures were used. Four copper-constantan thermocouples were attached to the subject's skin at the right calf and left thigh, stomach, and back. Two other thermo-

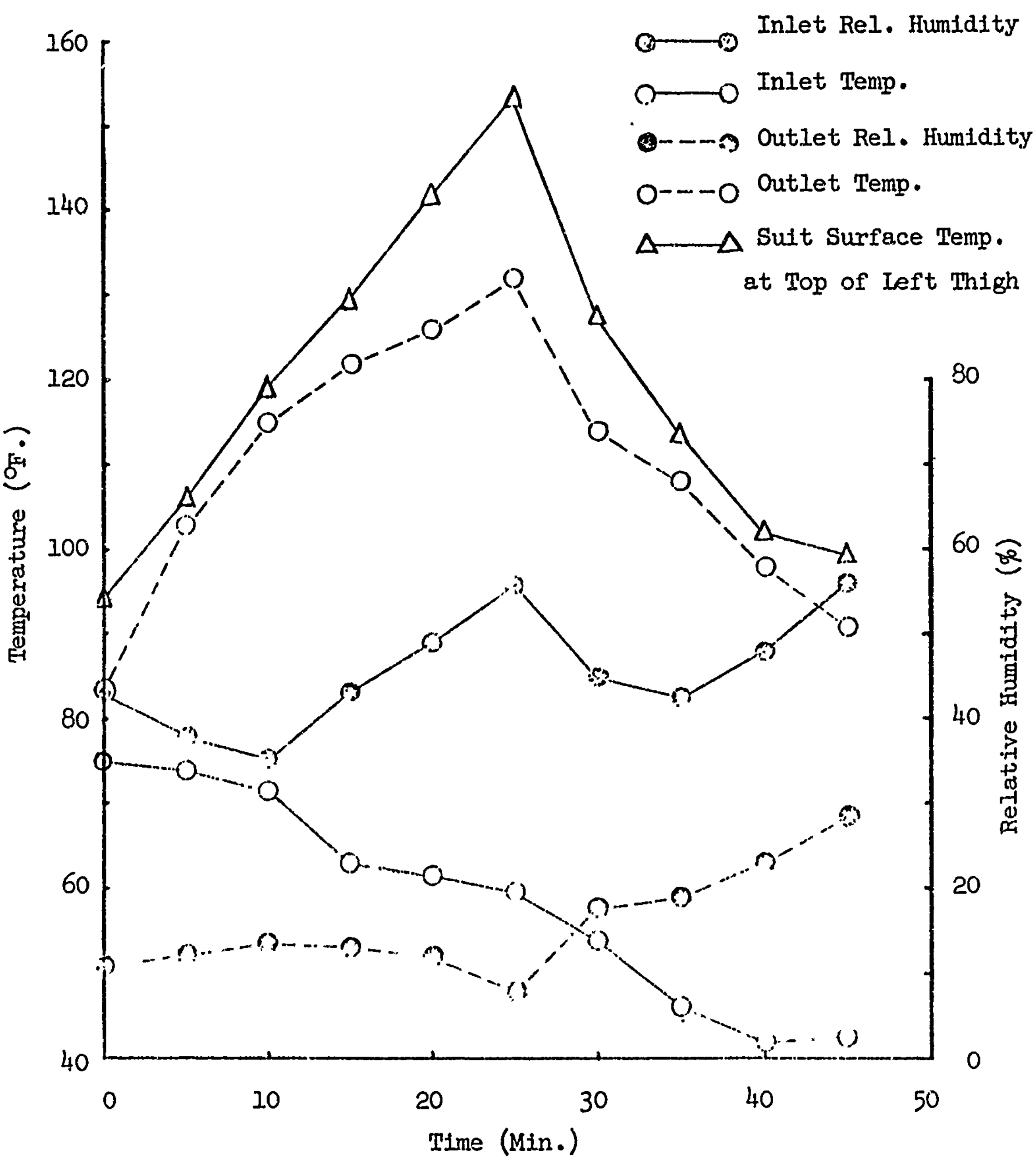

Figure 3. - AVERAGE TEMPERATURE AND RELATIVE HUMIDITY CHARACTERISTICS OF THE SUIT

couples were formed into a rectal lead for measuring body core temperature changes. By means of a Leeds and Northrup potentiometer, the temperatures were read off every 3 minutes and recorded. A difficulty arose because of differential heating of the parts of the plug-in junction for the rectal leads, causing them to misread during parts of the profile involving rapid temperature changes. As a consequence, this part of the physiological data is considered to be insufficiently accurate for presentation in this report. In addition, mercury thermometer measurements of oral and rectal temperatures were made before and after the heat exposure. To measure respiration rate, a Bourdon pressure gauge was located downstream from an orifice in the helmet air line so that a deflection in the gauge occurred upon each inhalation. For blood pressure, the transducer was placed under the pressure cuff and over the brachial artery, and then fed out of the chamber to a mercury manometer. A problem arose because of the slight pressurization produced by the ventilating air. This amounted to approximately 30 mm H_g. To counteract this, a line was placed in the suit which drew off a balancing pressure which was delivered to the top of the mercury column. These measurements were taken every six minutes. Electrocardiograph records were taken also. For this purpose, contact plates were fabricated of 1/8" brass cut to a 1" diameter and gold plated. Leads were placed on the chest and back. A third lead acted to ground the subject to the recorder and eliminate electrical noise. This was accomplished by using

the shield on one of the electrodes. The E.K.G. record was also used as the source of pulse rate data. The pilot-subject's water loss was measured by weighing him stripped before and after the heat exposure on a Fairbanks-Morse Beam Balance Scale accurate to one ounce. Additional safety equipment consisted of a 14" Kin Tel closed T.V.. 2-1/2 feet from the pilot's face, a voice intercom, a rapid disconnect on all physiological instrumentation, an Army cot, O_2 bottle, burn ointment, towels, and water. Because of the T.V. camera's temperature limit of 125°F., a separate refrigerated air supply was directed over it and the camera placed in an insulated aluminum case. Since performance measurements have been shown to be sensitive measures of stress effects, the devices involved in assessing the simulator performance can be thought of as both safety and data equipment. The accuracy of the flight performance was measured by comparing two electronic digital counters. One counter was set at a constant reference frequency. The other counter was set to count slower than the reference counter in direct proportion to the disparity between the scope signal and the cross-hair intersect. Flight coordination was measured by a circuit which closed to an indicator light in the cockpit and a Standard Timer on the data console whenever the rudder pedals or stick were over-controlled. There was an indicator light in the cockpit for both excessive rudder, i.e., "skid", and excessive stick, i.e., "slip". A series of runs in the unprotected condition were made, but all had to be aborted.

A Block Diagram of the system is shown in Figure 4.

B. Results.

1. Physiological - Unprotected Runs - The unsuccessful attempts to measure pilot response to the experimental environment in an unprotected condition will be reported on first. The following material was prepared by the Medical monitor at these tests, Dr. R. C. Armstrong

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MEDICAL DISCUSSION OF THERMAL TEST RUNS

UNPROTECTED CONDITION

The definition of physiological monitoring requirements for the unprotected exposures to high temperature environments was guided by the following principal factors. First, it was recognized that this experiment differed from any previously reported heat experiments in that the subjects would be exposed to a rapidly changing thermal environment designed to simulate thermal profiles as they would be encountered in operational situations in high performance vehicles. Results of previous Convair tests indicated that rapid rises in environmental temperature could produce subject responses out of proportion to the magnitude of the responses created by exposure to even higher environmental temperatures, when these temperatures were held relatively constant. Since our test was in this regard unique, optimum safety to experimental subjects demanded a more complete monitoring system than was required in previous tests. Each piece of monitoring equipment requested was essential to this effort. Consequently,

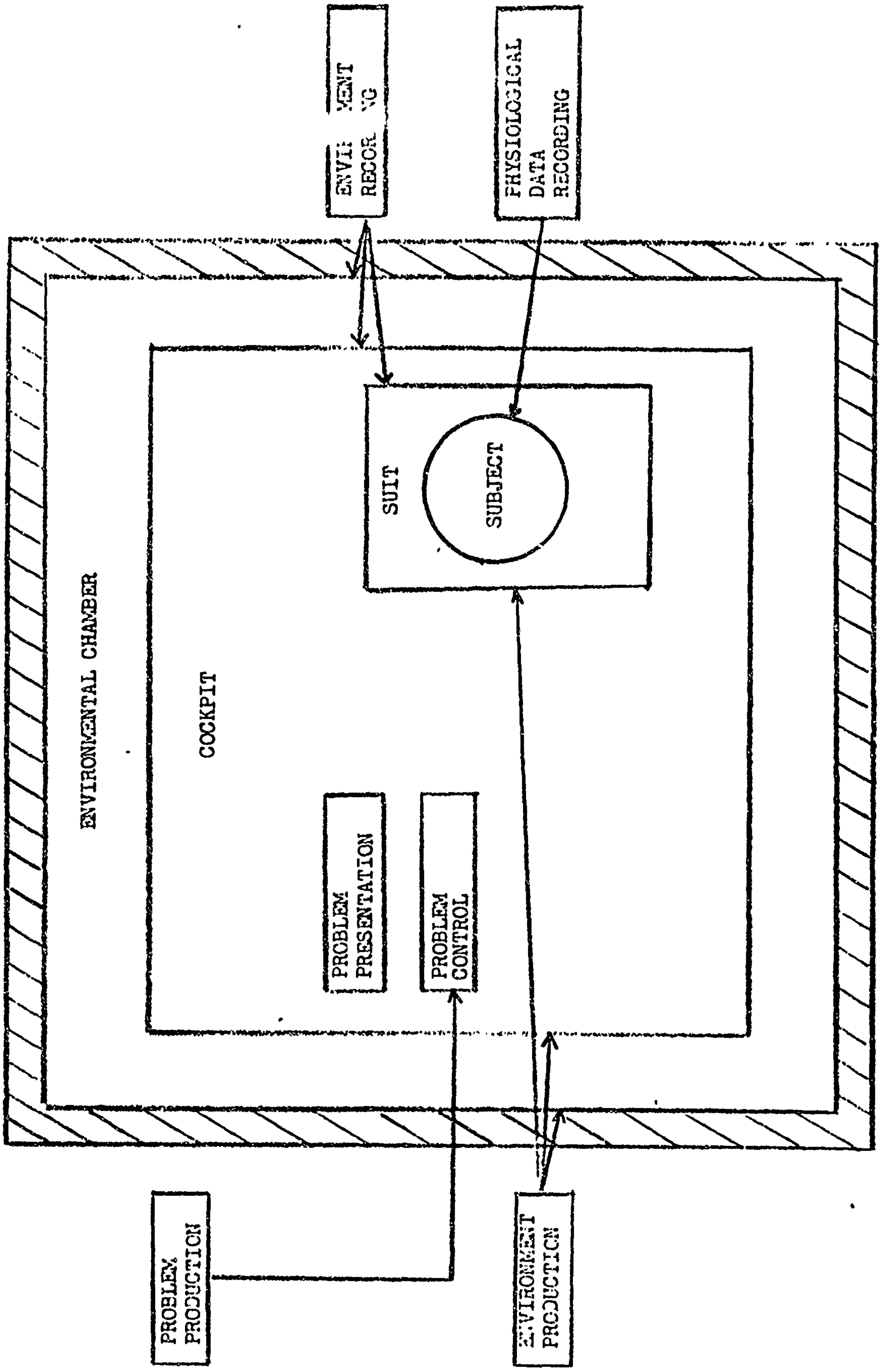

Figure 4.-SYSTEM BLOCK DIAGRAM

physical failure of any of the monitoring devices during an experimental run was sufficient cause to abort the run. This requirement for 100 percent operation of a complicated group of instruments under extreme thermal exposures proved to be technically impossible with existing equipment. Each heat run,in our unprotected series, was aborted prior to completion due to equipment failures. New techniques were developed by the test engineers employed on the study to raise the thermal tolerance of the instrumentation components. The technical experience gained was significant and subsequent tests (protected runs) were conducted for the programmed times without equipment failure, even though the heat loads on the equipment exceeded those encountered in the previously aborted runs. The unavoidable delays associated with these efforts made it necessary to discontinue thermal tests in the unprotected condition and move immediately to protected runs in order to conform with scheduled commitments. The physiological data presented on unprotected runs is, thus, understandably scanty and is limited to portions of two runs. Although these data are too few to warrant firm conclusions, certain important tendencies for human responses to rapidly changing thermal environments are indicated and merit some discussion.

In this report, the term unprotected runs refers to heat exposures of subjects dressed in conventional summer flying clothing. For example, a helmet, T-shirt and shorts, summer flying suit, gloves, and conventional foot gear. In contrast, protected runs infers heat exposures of subjects wearing a full-pressure ventilated suit. Figure 5 indicates the environmental temperatures utilized in the unprotected runs.

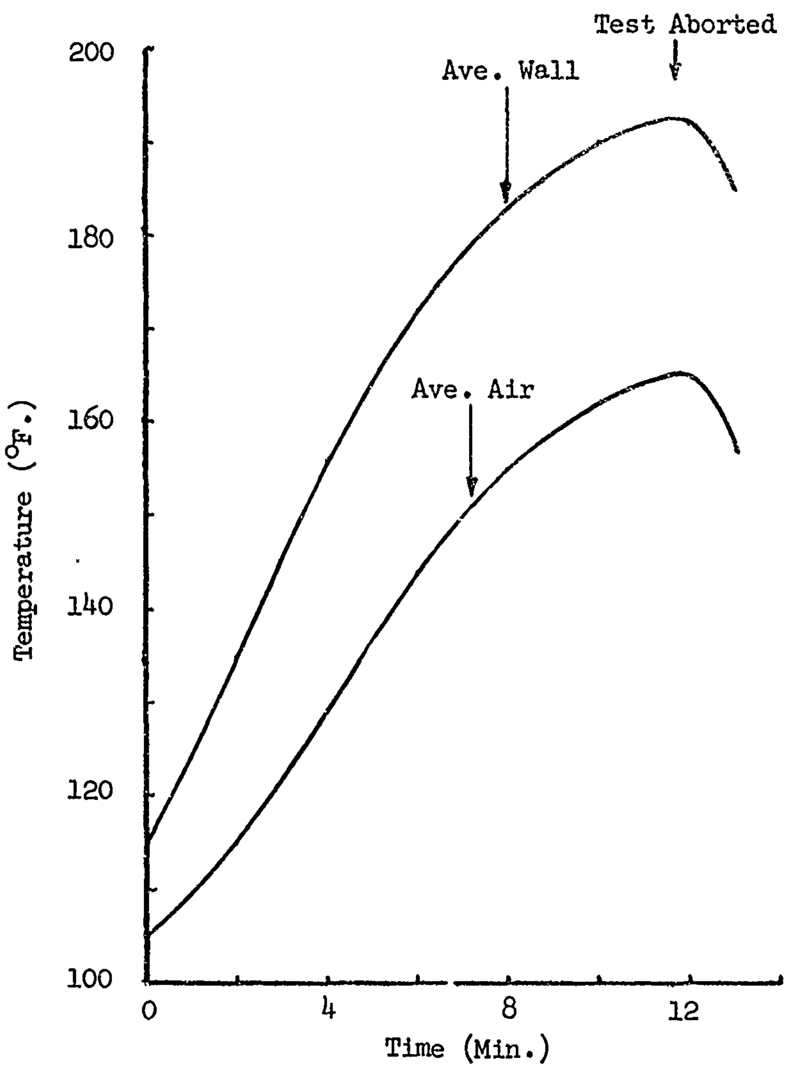

Figure 5. - ENVIRONMENTAL CONDITIONS DURING UNPROTECTED RUNS

Test Results

The following data and discussion apply to subjects, ages 28 and 29, who were tested in the unprotected runs. The general pattern of response of the two subjects was identical, so the following narrative description of the response of one subject can be considered to describe both runs. Physiological data presented on these two cases will be limited to measurements of blood pressure, pulse, and respiration. Measurements of skin and rectal temperatures of the subjects during the test were shown to be directly influenced by the temperature of the environment the thermocouples and plug-in leads were exposed to. These measurements, consequently, read higher than actual body temperatures and can not be presented as reliable data. It should be noted that even though the temperatures were inaccurate on the high side, they fell well within the normal range of tolerance. Oral and rectal temperatures measured by mercury thermometers immediately after the subjects left the heat chamber indicated a body temperature rise of only 1.2°F. to result from the thermal exposure.

Heat Test #1

Just prior to entry into the heat chamber the following physiological measurements were obtained on the subject:

Blood pressure	130/82
Pulse rate	92
Respiration	13 per minute
Oral temperature	98.6°F.
Rectal temperature	100.2°F.

A few minutes were required for the subject to enter the heat chamber and to plug in his physiological leads. Physiological measurements were then taken at three (3) minute intervals as shown on Figure 6. Figure 6 indicates the systolic and diastolic blood pressures, the pulse and

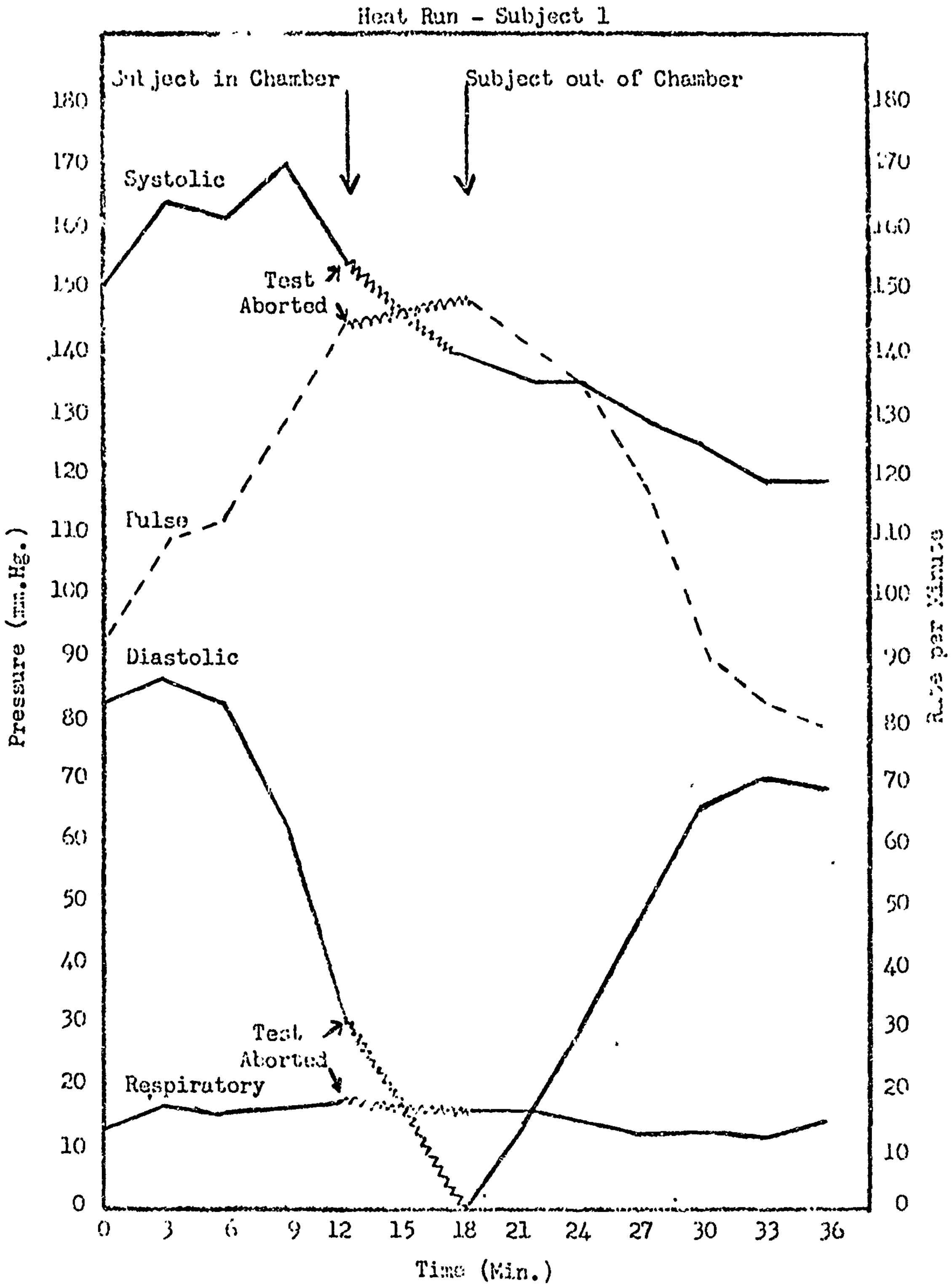

Figure 6.-PHYSIOLOGICAL MEASURES TAKEN ON SUBJECT 1; UNPROTECTED CONDITION

respiratory rates measured on this subject.

After about the third moment of testing, the electrocardiograph began to malfunction due to external electrical noise. This malfunction was intermittent but at about the twelfth moment of the test the electrocardiograph failed completely, and the test was aborted.

Coincident with shorting out of the electrocardiograph, a precipitous drop in diastolic blood pressure was noted on the subject.

The subject was removed from the thermal test facility into a cool environment, and his outer garments removed. Oral and rectal temperatures were measured by mercury thermometer and indicated that the body temperature had risen 1.2° F. throughout the period of heat exposure. A conventional pressure cuff was applied to the subject's arm and blood pressures taken at frequent intervals. A clearly audible systolic sound was heard at the brachial artery, and, although the sound lost intensity with lowered cuff pressure, it was clearly heard to zero cuff pressure. Repeated blood pressure measurements, as indicated on Figure 6, show that the diastolic pressure rapidly returned and steadily increased back to the normal pre-test level, although the subject had a zero diastolic pressure, as measured by conventional means, (sphygmomanometer and stethoscope) there were neither signs nor symptoms of reduced circulation. The subject maintained a strong regular pulse, a normal respiratory rate, and a warm, perspiring, flushed skin. Throughout this period the subject was mentally alert, indicated no decrement in motor performance, and was entirely free of symptoms other than the warm sweaty feeling common to heat exposure. The only adverse symptom reported by the subject, either at this time or later, was a feeling of mild fatigue following the exposure. This fatigue was of rela-

tively short duration, and was not noted the day following the exposure. A second subject, in a later run disclosed a similar pattern of responses to the rapidly changing thermal environment. This subject's measurements are shown on Figure 7. This second subject also had a rapid drop of diastolic blood pressure to zero as measured by our conventional indirect auscultatory methods. He also failed to denote either signs or symptoms of a reduced circulation. The electrocardiogram record obtained on the 2 subjects during the period of heat exposure and the period following removal from the test facility failed to denote any significant changes. There was a moderate flattening of the T-waves which is commonly noted in thermally stressed subjects.

Complete blood counts and urinalyses were obtained on the subjects prior to and following thermal exposures. No significant changes were noted in the post-test specimens.

Hematocrits obtained following thermal exposure were less than 1 percent higher than pre-exposure values.

Erythrocyte sedimentation rates measured immediately after the test runs and one week later disclosed no significant change from pre-exposure values.

Plasma and urine samples were obtained prior to and following the tests, and were prepared in frozen form for a later determination of adrenalin, nor-adrenalin ratio. These samples are being processed as a part of another study, and the data has not been obtained for inclusion in this report.

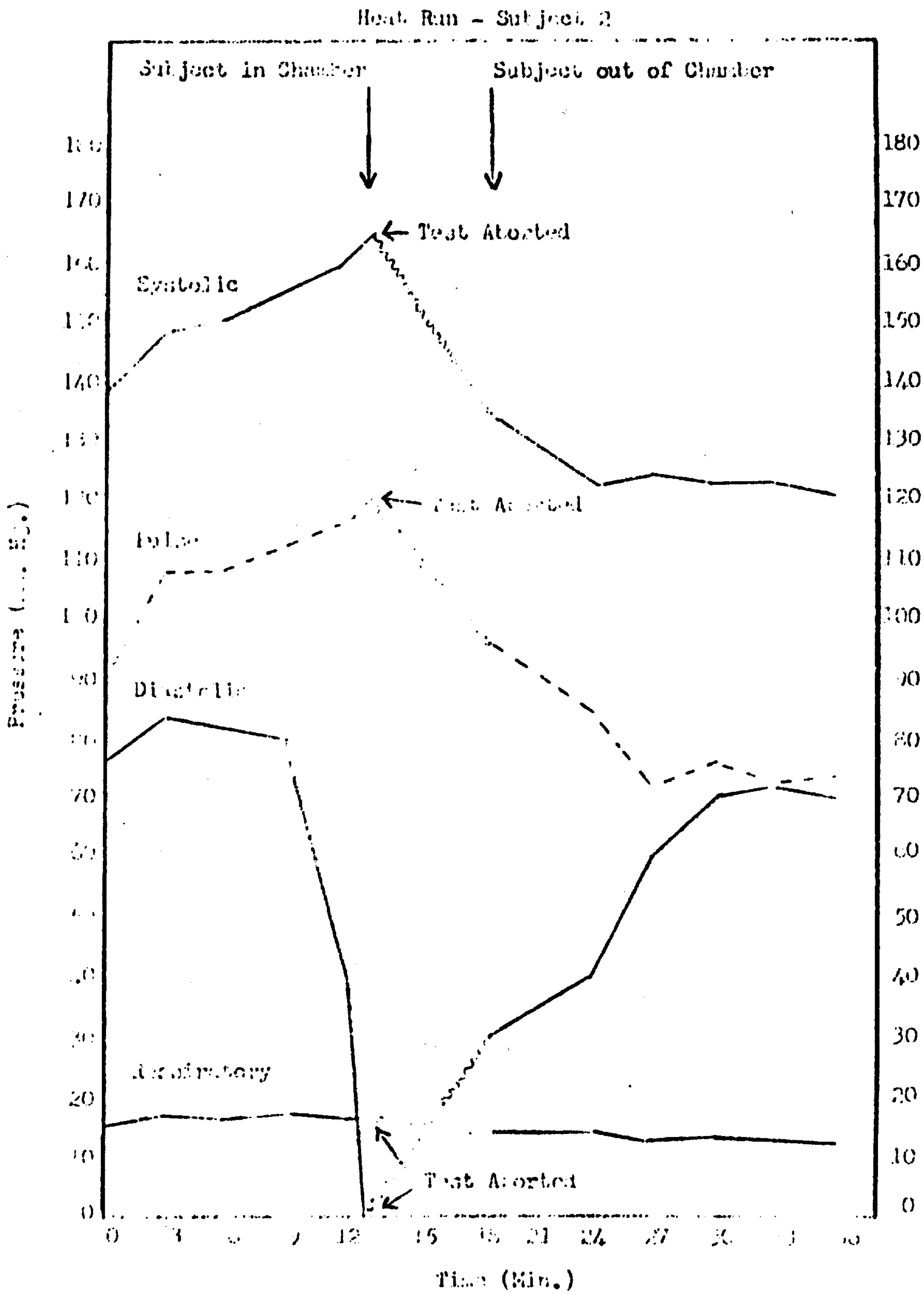

Figure 7. - PHYSIOLOGICAL MEASURES TAKEN ON SUBJECT 2, UNPROTECTED CONDITION

Discussion of Experimental Results

The physiological, psychomotor, and laboratory measurements obtained on these two subjects undergoing thermal stress were all unremarkable, except for the blood pressure measurements. The pattern of blood pressure response to this pulse-type thermal exposure, as measured on these two subjects, differs from responses previously reported in thermal experiments. This difference is quantitative but not qualitative, and is an anticipated response as indicated in the following discussion.

Heat exchange between the subject and his environment takes place at the body surface. Internal body heat is carried in large part to the body surface by the blood. In response to increased body heating, the blood vessels of the skin dilate to increase the flow of blood to the surface to enhance heat transfer. The result is an increased volume of blood within the system of vessels, and a decreased resistance to flow. The manner in which this resistance is lowered can be shown by the following formula which applies to fluid flow through simple uniform pipes:

$$R = \frac{n \cdot L}{D^4}$$

Where R = resistance
n = viscosity of the fluid (blood)
L = length of the tubes (vessels)
D = inside diameter of the tubes (vessels)

Viscosity of the blood is affected, to a large extent, by the proportion of cellular elements present in the blood. Our measurements of blood hematocrits disclosed no significant change following thermal exposure, so in general, viscosity or n may be considered to be relatively constant for purposes of this discussion. L, the length of the vessels, will tend to increase to some extent, due to opening up of additional small vessels

of the skin in response to increased flow. D, the inside diameter of the vessels, will show the greatest change. Physical evidence of this dilatation was noted in the subjects by the marked flushing, or redness of the skin, after thermal exposure. This increased skin coloring is directly related to the increased amount of blood near the surface, in the dilated, superficial vessels. With viscosity and vessel length both being linear factors and both being relatively constant under conditions of thermal stress, and with a marked vessel dilatation, with an effect increased to the fourth power, it is readily apparent that resistance to flow under these conditions will be markedly reduced. The diastolic blood pressure (the blood pressure measured when the heart is resting between beats) therefore rapidly falls off as the blood freely flows from the arterial system where the pressure is measured into the low pressure system of veins that returns blood to the heart. The relationship of blood volume flow V, blood pressure P, and the resistance factor can be approximately expressed by the following equation:

$$V = \frac{P \cdot D^4}{L \cdot n}$$

As the effects of L and n, vessel length and viscosity, were previously indicated to be relatively insignificant compared to the effect on dilation for general purposes this relationship can be shown by the following equation:

$$V = k \cdot P \cdot D^4$$

Since, in this equation, both volume flow and pressure are shown to be linear, with respect to the exponential factor, D^4, it follows that volume flow would show a marked increase with a constant or even reduced blood

pressure when dilatation occurred.

Obviously, these equations for flow through simple, uniform pipes do not accurately describe the physiology of circulatory dynamics. However, these physical principles do apply and suffice to explain why lower diastolic blood pressure is expected in heat stressed individuals.

Markedly lowered or zero diastolic blood pressure is found in subjects with circulatory stress from causes other than heat exposure. For example, zero diastolic pressure may be found in subjects with aortic valvular insufficiency. Very low diastolic pressures are found in persons with an arteriovenous shunt or fistula, thyrotoxicosis, and others. In such subjects, these conditions may exist for prolonged periods (years).

The increased heart rate accompanying thermal stress is likewise a normal adaptive response required to accommodate the increased volume of blood that must be pumped to maintain circulatory equilibrium.

The moderate rise in respiratory rate may be explained by the increased metabolic rate of the subjects during the test. The motor activity required to perform the simulated flying task, plus an approximate 7 percent increase in metabolic rate per F. degree rise in body temperature would evoke a moderate increase in requirements for oxygen and carbon dioxide exchange.

In general, the physiological responses of these subjects were all normal adaptations to thermal stress and were to be expected. However, even though diastolic pressure drop is qualitatively normal, the response in these subjects was out of proporation to the drop expected considering the magnitude of environmental temperature to which they were exposed. In

other experiments, subjects have been exposed to much higher temperatures for much longer periods of time with only moderate lowering of diastolic pressure. In these other experiments, however, the temperatures were held constant and the level of difficulty of the psychomotor task performed by the subjects was less. Several possible explanations for our unique findings are evident.

(1) Only two test subjects were involved, the response of these two subjects may not be representative of the average response to thermal stress of this type.

(2) A rapidly changing thermal environment may cause neurocirculatory responses by either physical or psychological effects which differ quantitatively and to some extent qualitatively from responses to an external thermal stress of constant magnitude.

(3) The high level of physical and mental responses required to perform the simulated operational pilot task may potentiate thermal stress responses.

(4) Our indirect method of measuring diastolic blood pressure may be unsatisfactory under conditions of markedly increased blood volume flow rates. It is possible that high rates of blood flow through vessels may produce sounds audible to a sensitive stethoscope even in the presence of an intact diastolic pressure.

Conclusions

These data, presented on the unprotected thermal runs, are too few to provide a firm basis for conclusions. Unique physiological responses to pulse-type thermal exposure were disclosed in the two subjects tested

under these conditions. These experiments point to a need for similar experimentation on a larger group of test subjects with the now-improved monitoring equipment to better define these responses and their effects upon tolerance. Direct measurements of blood pressure (cannulization) during such experiments should be considered.

- -

B. 2. Physiological-Protected Runs - The physiological data on the suited runs are shown in Figures 8 through 14. The training score is considered to be a control condition. It represents the data of the last training trial with the suit on under ambient temperature conditions. Figures 8, 9, 10 and 11 show average skin temperatures. Figures 12 and 13 present the blood pressure data. Figure 14 presents pulse rate data for the test and control conditions. It is of interest to note the tendency for the measures to be higher at time zero under the heat test. This can be partially attributed to the subject's walking through the high temperature chamber to the cockpit, partially to the environmental conditions in the cockpit prior to starting a heat test, partially to the delay involved in hooking up the vent supply to the suit, and partially to the anticipatory tension of the subject.
The following represents the analysis of the medical observer at this series of tests, Dr. W. L. S. Wu.

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MEDICAL DISCUSSION OF THERMAL TEST RUNS
PROTECTED CONDITION

In discussing environmental temperature effects, it is necessary to consider at the same time the synergic effect of environmental humidity. We note that the relative humidity curve for inlet air is also peaked while that for outlet air is nearly an inversion of the above curve on a lower level.

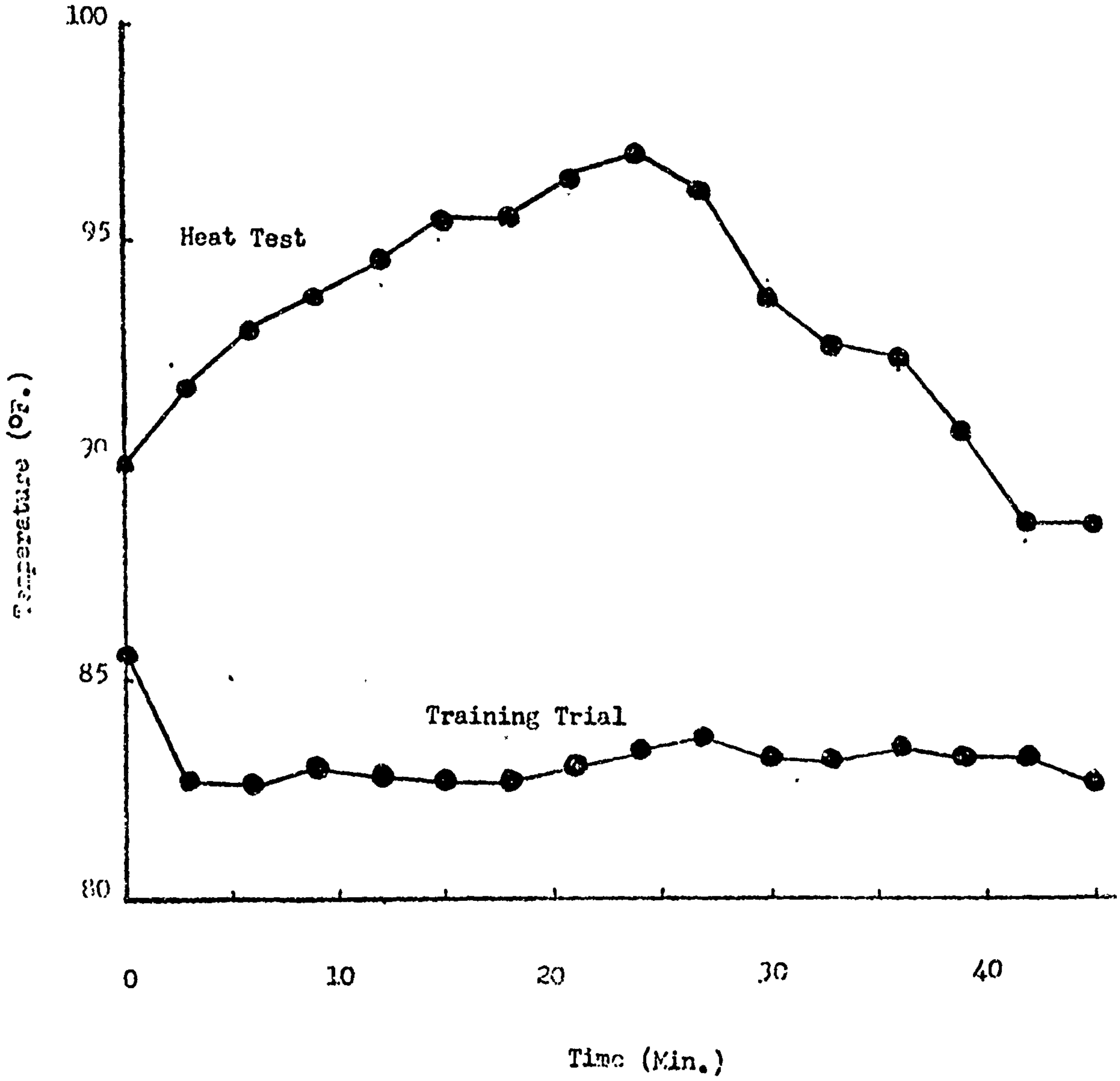


Figure 8.-AVERAGE SKIN TEMPERATURE ON THE BACK DURING HEAT TEST AND FINAL TRAINING TRIAL

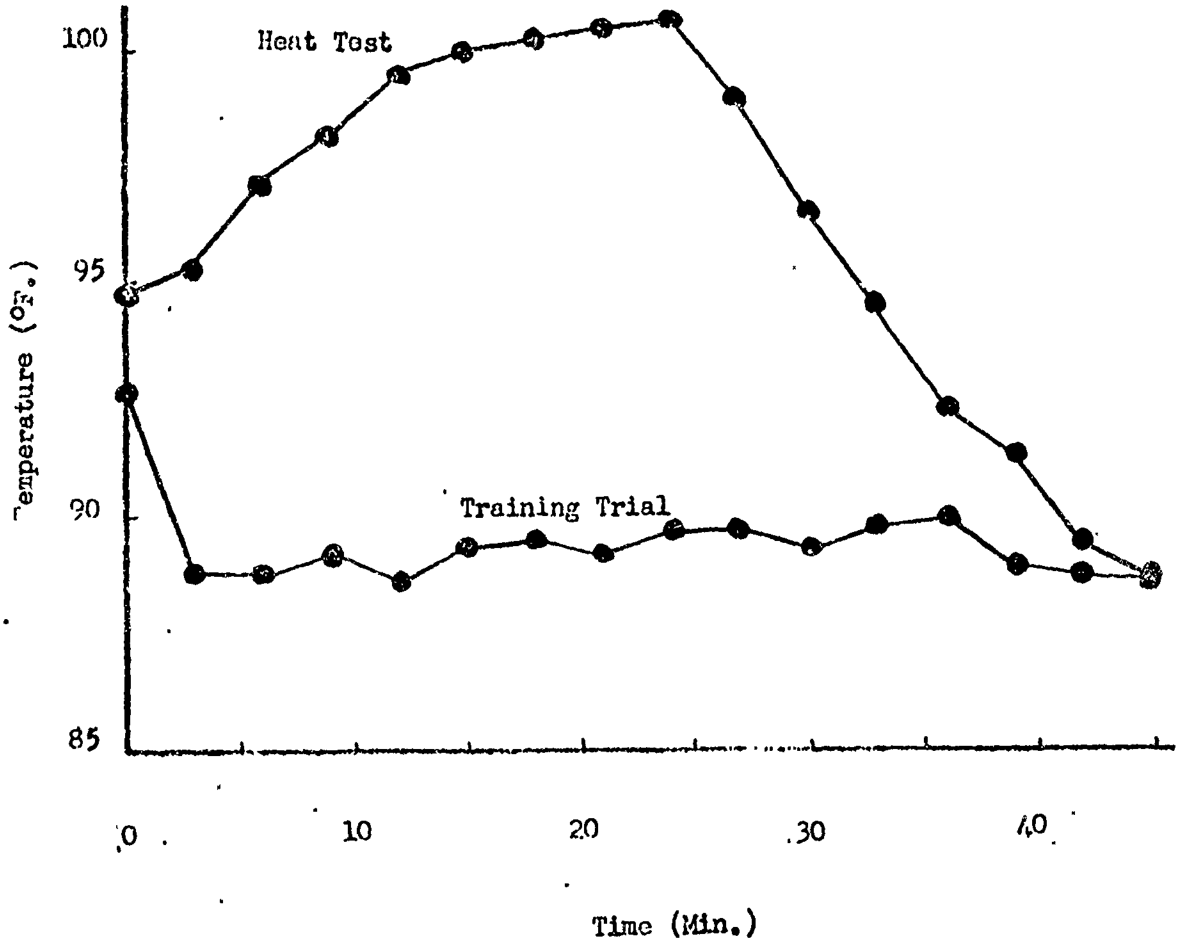


Figure 9.-AVERAGE SKIN TEMPERATURE ON THE STOMACH DURING HEAT TEST AND FINAL TRAINING TRIAL

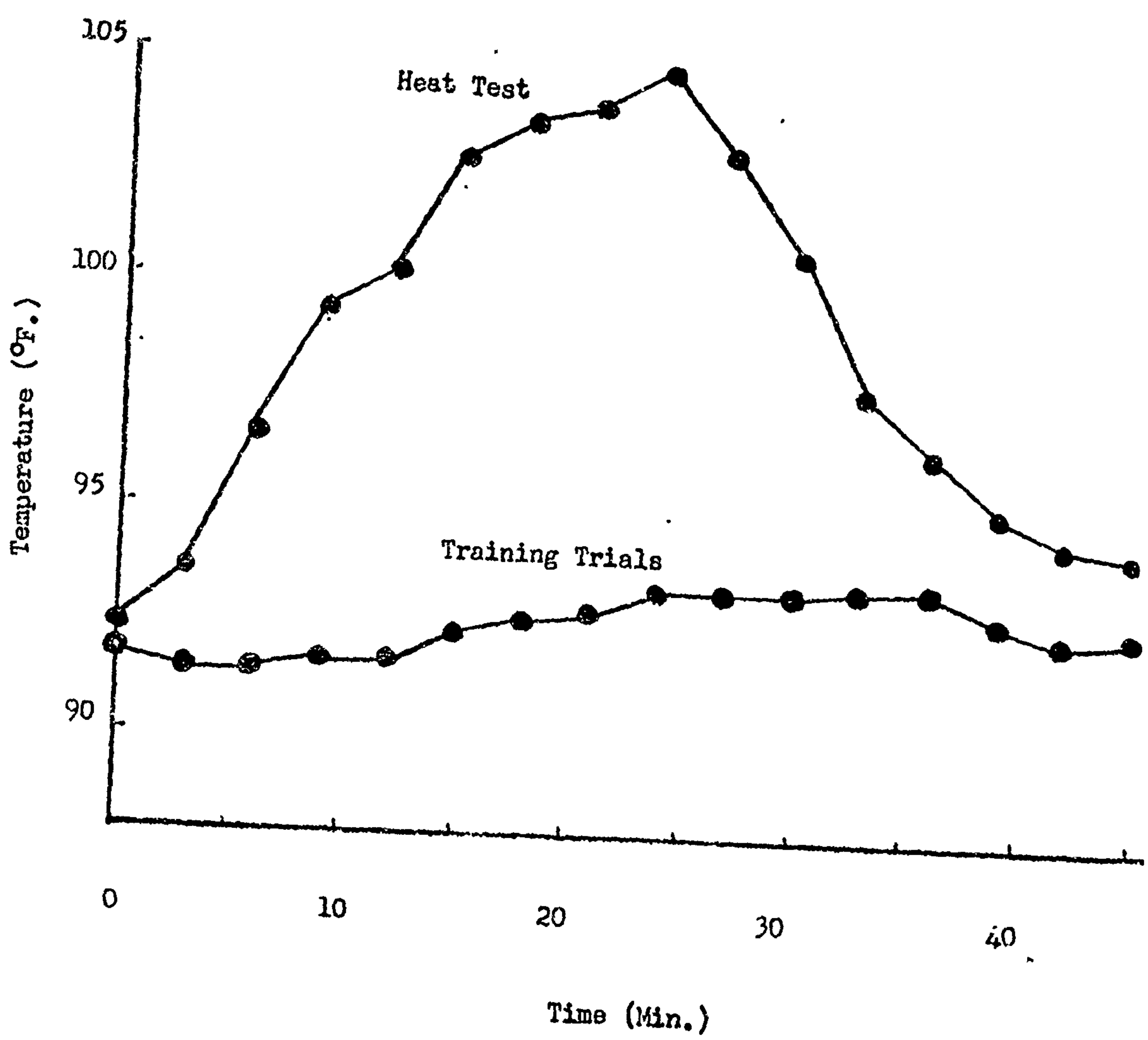


Figure 10.-AVERAGE SKIN TEMPERATURE ON THE THIGH DURING HEAT TEST AND FINAL TRAINING TRIAL

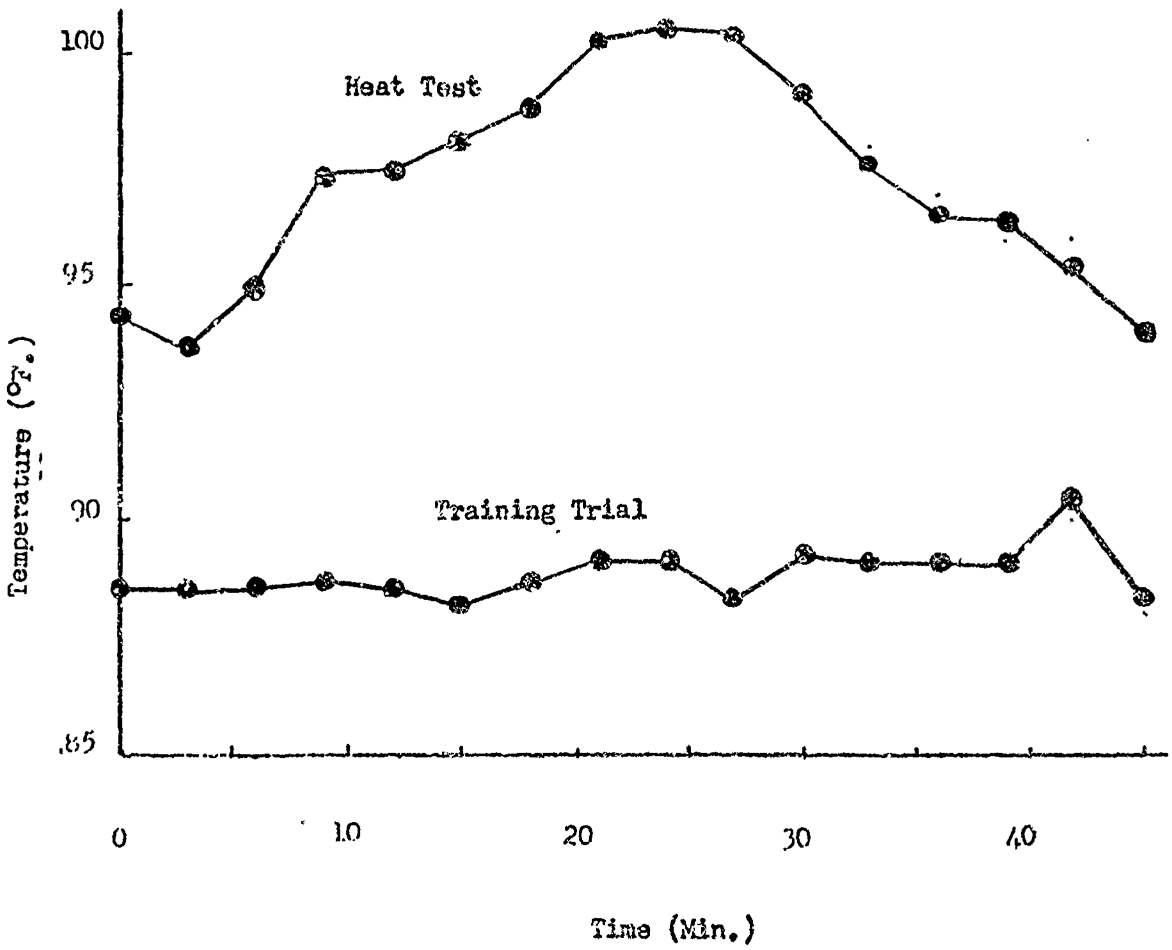


Figure 11.-AVERAGE SKIN TEMPERATURE ON THE CALF DURING THE HEAT TEST AND THE FINAL TRAINING TRIAL

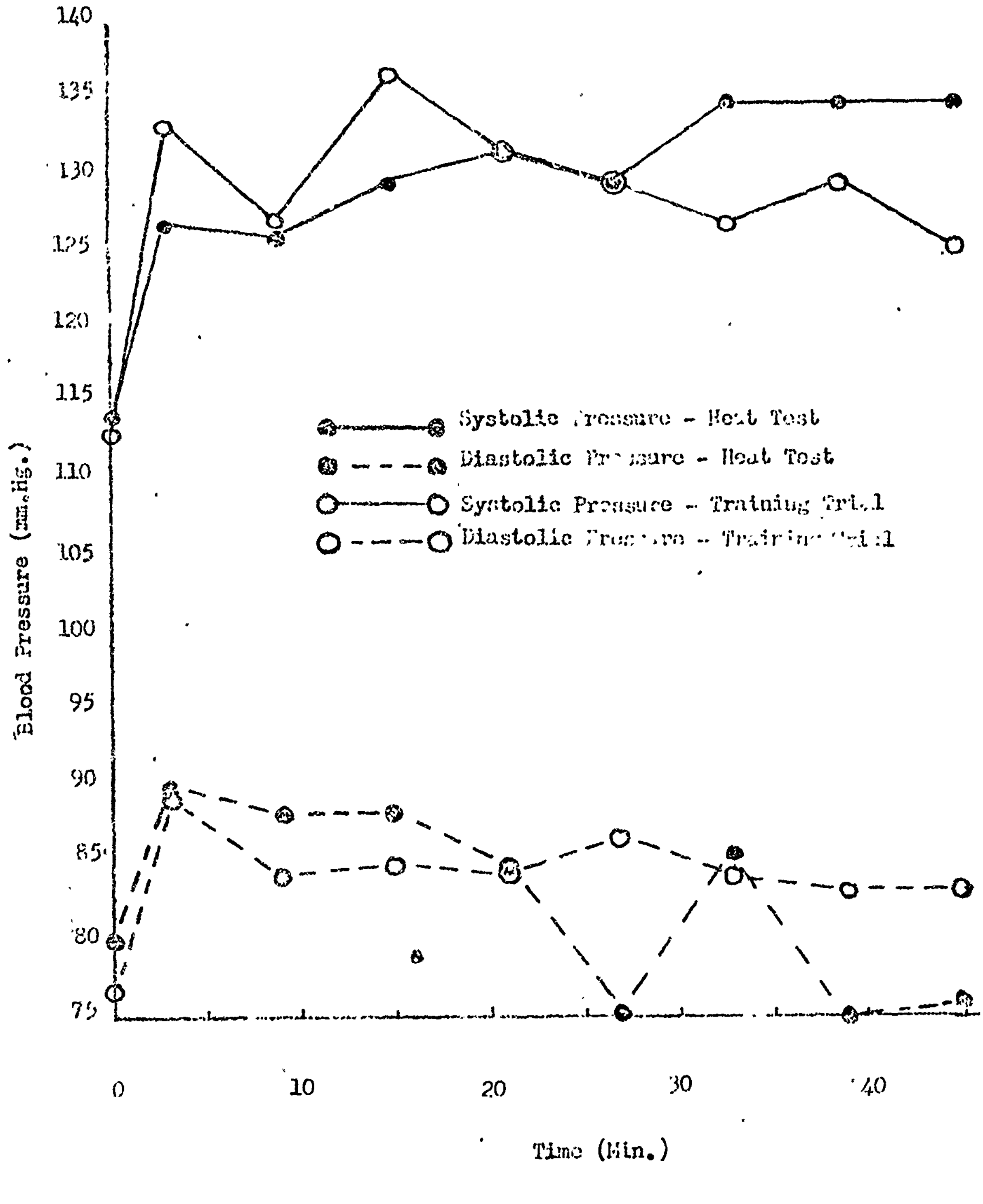


Figure 12.-AVERAGE BLOOD PRESSURE DURING HEAT TEST AND FINAL TRAINING TRIAL

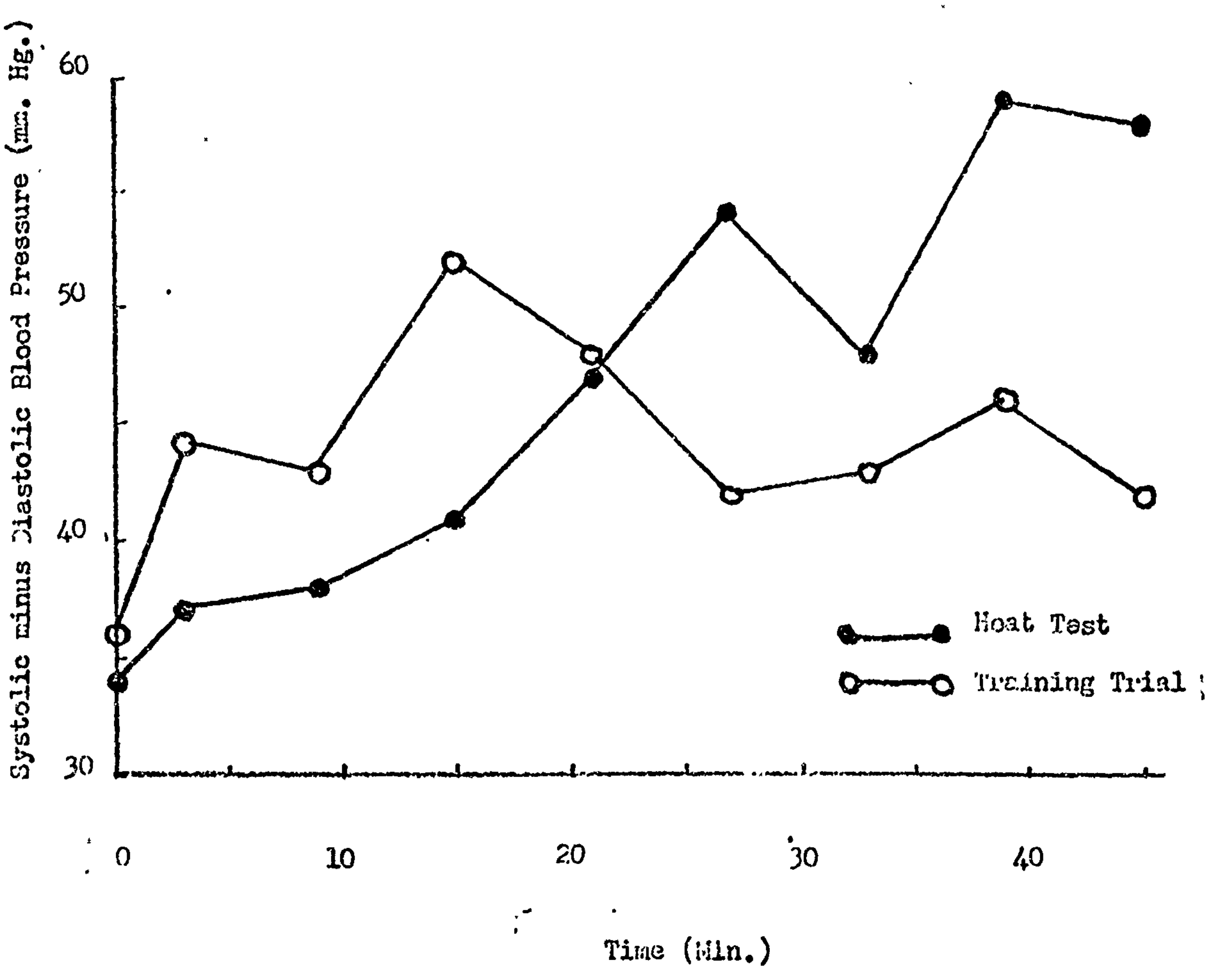


Figure 13.-DIFFERENTIAL PULSE PRESSURE FOR TRAINING AND TEST CONDITIONS

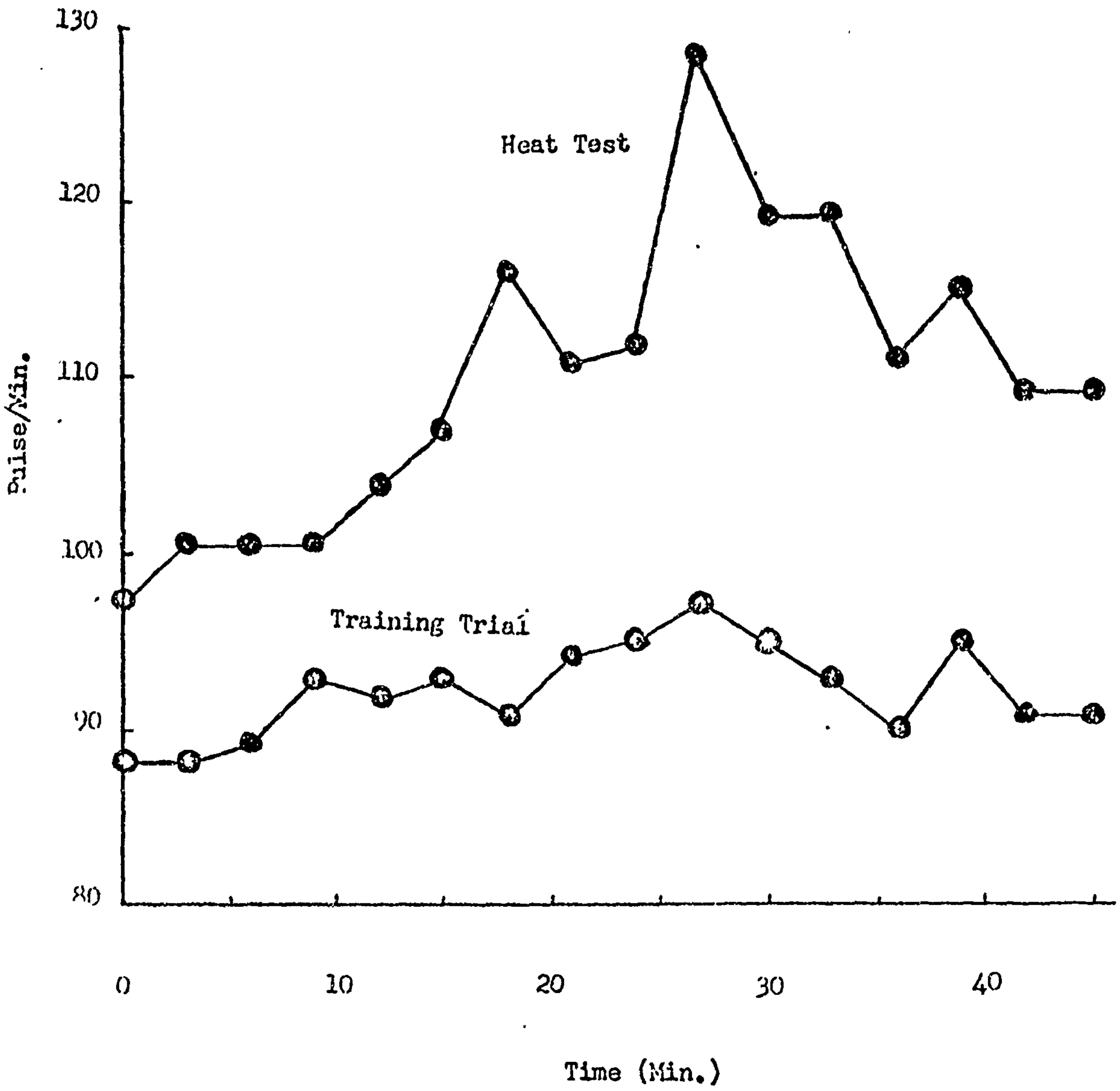


Figure 14.-AVERAGE HEART RATE DURING THE HEAT TEST AND FINAL TRAINING TRIAL

The net average effect caused by humidity on the experimental subjects by restricting free evaporation and heat loss from their skin surfaces should be approxi- ' ɔnstant (representable by a straight line). However, the higher level of absolute humidity which prevailed throughout the experiments is expected to decrease their heat tolerances. In other words, had the absolute humidity been lower, the same subjects would have tolerated higher temperatures without discomfort in the same protective suit, provided that the thermal experiment was not sufficiently prolonged to cause significant dehydration.

Among all the temperature measurements, the average skin temperature reflects the actual thermal stress on the test subjects most closely. It has the same peaked appearance as four other environmental temperature curves, only much more gentle in degree (varying between 90 - 97°F.), as to be expected.

The same cannot be said about the average rectal temperature, as measured in this particular experiment. Because of instrumentation problems mentioned previously these readings contain too many artefacts for accurate interpretation. However, in two of the subjects, the highest rectal temperature never exceeded 101.5°F., well within physiological tolerance limits. Therefore, the conclusion is justified that the Navy ventilated suit is quite capable of rendering effective protection to the subjects under the particular experimental thermal stress conditions.

The respiratory rate remains fairly constant throughout the experiments, between 12 - 20 per minute, in all 3 subjects. As readily visualized by the needle fluctuations of the respirometer, each individual subject actually breathes rather irregularly from time to time, due to voluntary control or less conscious reflexes. Thus, both holding of breaths and

hyperpnea were frequently noticed although not to any important, patholog-ical degree to indicate any significant non-physiological stress.

Upon superficial examination of the physiological data, it might be said that the systolic and diastolic blood pressures tend to show a slight, irregular rise and fall respectively up to the time of the peak thermal load and after that, return slowly to normal. These readings become immediately much more impressive if their differences are graphed against the thermal load. The pulse pressures would then show progressive widening to reach a peak at 27 - 30 minutes coincident with the thermal peak. This is a good indication of progressive, peripheral vasodilatation as a compensatory mechanism for the physiological dissipation of heat.

It is interesting to note that the degree of weight loss, reflecting primarily the amount of water loss through evaporation, seems to be somewhat greater with those subjects showing a greater degree of peripheral vasodilatation; i.e., widening of pulse pressure. However, a definite conclusion cannot be made with only three (3) subjects.

It is also interesting to note that the heart rate also increases progressively with increase in thermal load to reach a peak at about 27 minutes. The average increase in the few subjects of this series is about 30 beats per minute and recovery therefrom seems to be somewhat slower, as is the case with most physiological data discussed above. This phenomenon may or may not be compensatory since the actual increase in cardiac output per minute, therefore, in peripheral circulation, with tachycardias at a rate of between 120 - 140/minute is more or less academic, depending upon venous return in addition to diastolic filling.

Since all the electrocardiograms have been taken with a pair of bipolar chest leads located as described previously and there have been no essential alterations in their gross configurations, the more subtle changes can be best compared by means of tabulated data on a separate page. The following discussion refers to that table.

V.R. indicates ventricular rate and S.A. indicates sinus arrhythmia which was never very much. Zero mm. P waves are almost isoelectric. The generally low P and T waves are due to the relative electrode positions and of no significance. However, both showed slight lowering throughout the experiments, particularly the T waves. There seems to be some relative lengthening of the PR interval in 2 of the 3 subjects, if increase in heart rate is given simultaneous consideration. Ventricular depolarization complexes are remarkably unaffected by the peak thermal stresses in all subjects. Only slight shift in R-S heights was noted in one subject, presumably due to slight shift of the position of the heart inside the chest, thus affecting the vector loop and its directional component. ST segment shift has not been more than 1 mm. total and that, only in one subject. This is of no significance. The T waves are lowered from 1/2 - 2 mm. in all 3 subjects, signifying possibly slight myocardial ischemia. Whether there has been any absolute shortening or relative lengthening of the QT interval, or indeed, if there has been any significant change at all after the QT has been connected for the ventricular rate (QTc), is highly debatable from the data presented. The somewhat increased QT ratio (QTr) in one subject may be explained on the basis of slight myocardial ischemia and/or electrolyte disturbances. An overall conclusion of good tolerance of all subjects in the protected condition toward thermal stress from the purely electrocardiographic viewpoint is, therefore, justified.

TABLE I - ANALYSIS OF ELECTROCARDIOGRAPH DATA

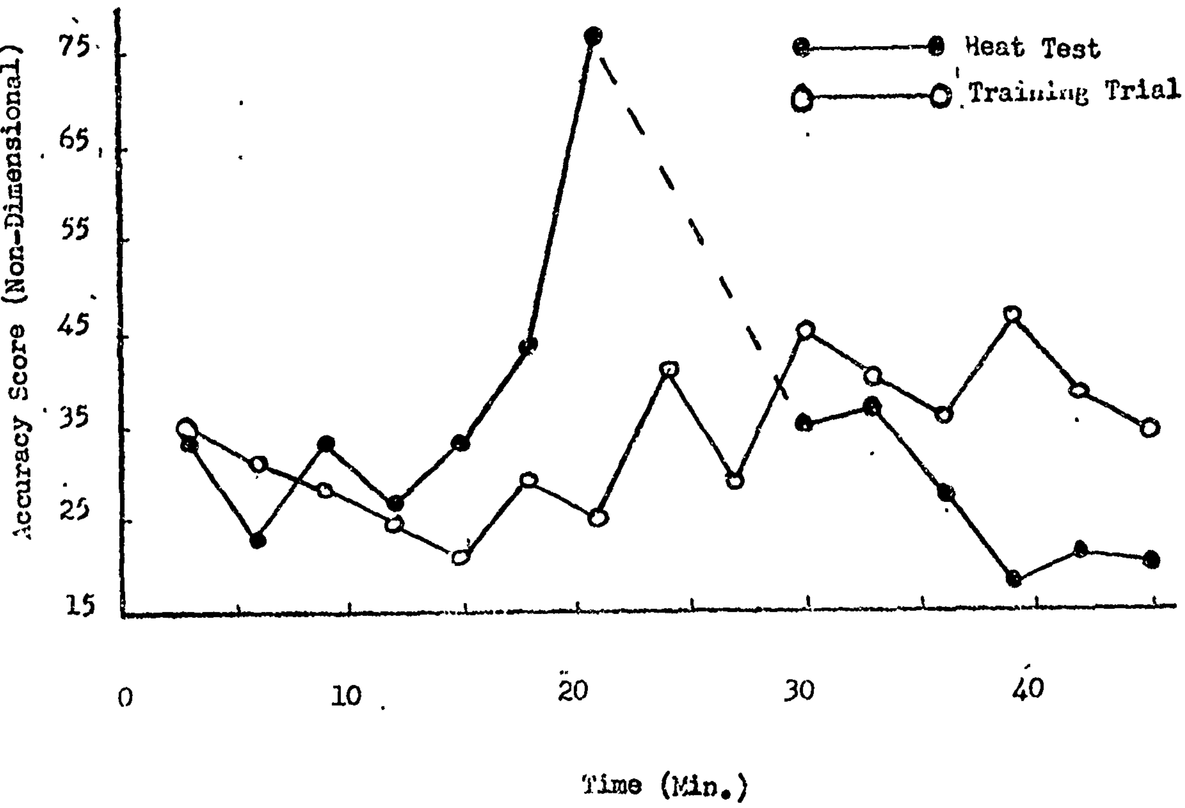
	(Units)	Subject #1	Subject #2	Subject #3
		Baseline Electrocardiograms (Protected Runs)		
R-R	sec.	0.8	0.75	0.72
VR	per minute	75.	80. (S.A.)	83.
P	mm.	0.2	0.2	0.3
PR	sec.	0.17	0.16	0.13
Q	mm.	—	0.5	—
R	mm.	8.5	12.	8.5
VAT	sec.	0.03	0.04	0.04
S	mm.	4.5	1.	2.
QRS	sec.	0.09	0.06	0.08
ST	mm.	0.	+0.5	0.
T	mm.	+1.7	+3.5	+2.
QT	sec.	0.38	0.36	0.34
QTe	sec.	0.43	0.42	0.4
QTr	Ratio	1.06	1.04	1.
	Units	Peak Thermal Load ECG (at 27 minutes)		
R-R	sec.	0.54	0.38	0.54
VR	per minute	111. (S.A.)	158.	111. (S.A.)
P	mm.	0.	0.	0.3
PR	sec.	0.18	0.13	0.12
Q	mm.	—	1.	—
R	mm.	8.	8.	8.5
VAT	sec.	0.03	0.04	0.04
S	mm.	8.	2.	2.
QRS	sec.	0.1	0.06	0.08
ST	mm.	0.	-0.5	0.
T	mm.	+0.5	+1.	+1.5
QT	sec.	0.34	0.25	0.32
QTc	sec.	0.46	0.41	0.43
QTr	Ratio	1.15	1.03	0.93

Among the subjective comments, the following may be quoted. "It is difficult to tell whether it is more comfortable with or without the protective suit. Contrast between hot and cold spots are more definite with the suit instead of being hot all over without the suit." "The back of the hands becomes too hot to handle the controls." "For a while, it is difficult to take normal breaths."

On examining the subjects immediately after their coming out of the heat chamber, they all showed flushing of the face, injection of the bulbar conjunctival, and marked pupillary dilatation. Several skin areas have become pink from the "hot spots." These included the back of the neck, underneath the shoulder straps, around the thumb and back of the hand, and over the patella. In no case did these mucocutaneous irritations approach an intolerable degree under the protective suit.

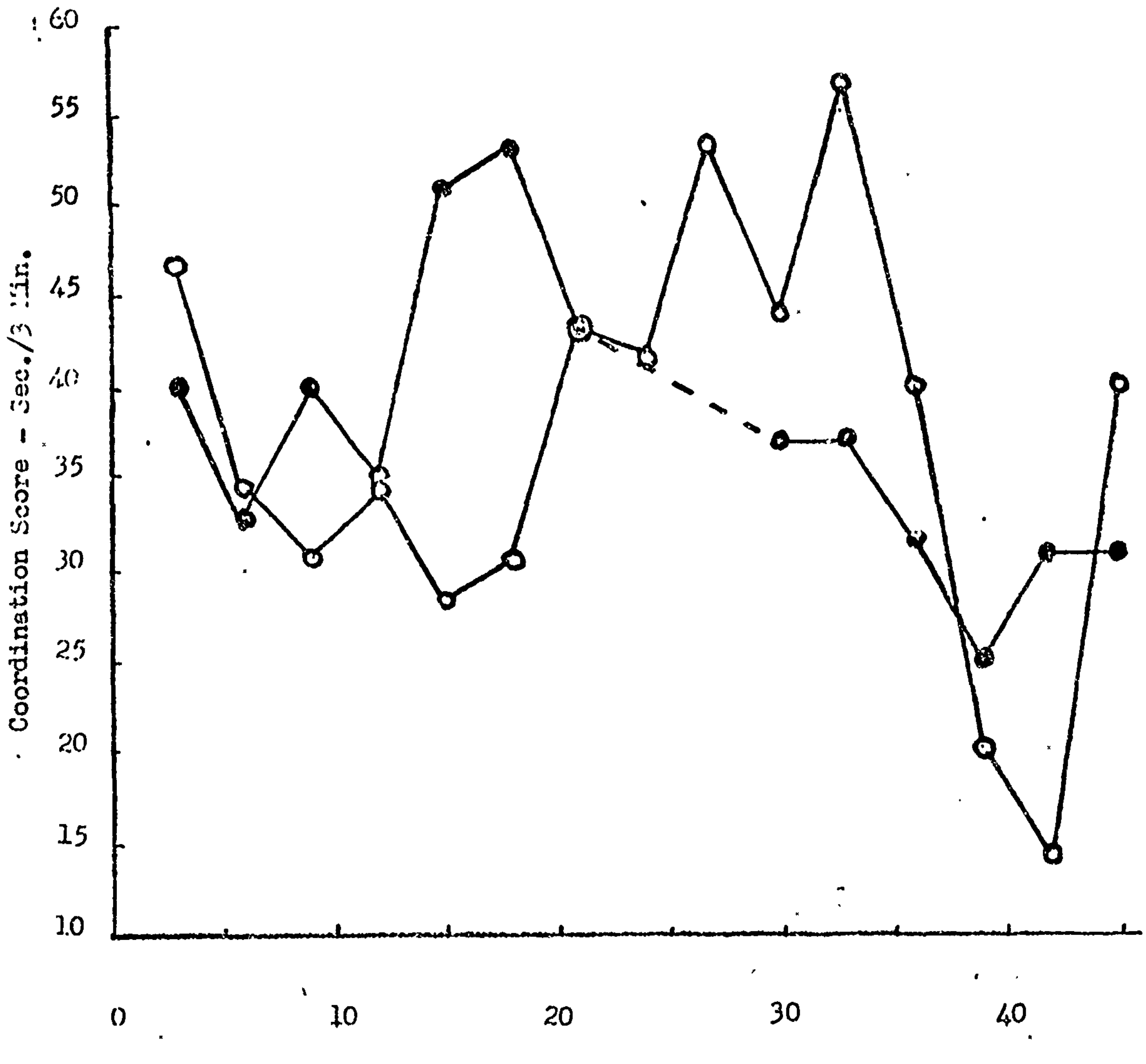
B. 3. Performance and Subjective Data - Figures 15 and 16 present the coordination and accuracy scores of the pilot subjects during the final training and test runs. Except for a departure at the twenty-first minute caused by excessive heating of the hand on the control stick, there is virtually no indication of a performance decrement attributable to the thermal conditions.

The subjective comments of the subjects give some clues to the design problems to be anticipated in attempting to provide adequate personal equipment protection for envir nments of the type employed in this investigation. The great majority of subject complaints



Note: The lower the score, the higher the accuracy. The dotted line indicates a point in the heat test when subjects removed their hand from the control stick.

Figure 15.-AVERAGE FLIGHT ACCURACY SCORES DURING HEAT TEST AND FINAL TRAINING TRIAL



Note: The lower the score, the better the coordination. The dotted line indicates a point in the heat test when subjects removed their hand from the control stick.

Figure 16.-FLIGHT COORDINATION SCORE DURING HEAT TEST AND FINAL TRAINING TRIAL

following a run concerned the conductive heating of the body parts which came into snug contact with the suit. Particularly troublesome in this respect were hands, knees, and shoulders. By means of polyurethane inserts, it was possible to greatly reduce this difficulty. Research work is indicated on the development of materials which have high radiation rejection properties and low thermal conducitivity.

CONCLUSIONS

1. Dynamic temper   ulation of high performance and space vehicle capsule en ironments for the purpose of human habitability testing is very difficult but possible.

2. Rapidly changing temperature environments characteristic of some high performance and space vehicle cabins may produce physiological problems not encountered in steady temperature tests. Further research on this question is required and is underway.

3. The Goodrich Mark III ventilated full-pressure suit appears capable of making the test environment habitable for pilots, though several useful re-designs and improvements are suggested by the data.

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